

Radiation-Mediated Plasma Stability: Testing a Quantum-Thermodynamic Hypothesis with Astrophysical Data

Prof. Dr. Md. Faridul Islam Chowdhury, MBBS, MS (Neurosurgery)
Neurosurgeon, Neuroscientist, Theoretical Cosmologist
Founder and Director, Tanfarid Vision Research Institute, Bogura, Bangladesh
Inventor of the Tanfarid Quantum-Thermodynamic Universe (TQTU)
ORCID: 0000-0003-3178-0671

Abstract

This study investigates a novel hypothesis within the Tanfarid Quantum-Thermodynamic Universe (TQTU) framework, proposing that continuous radiation flux may contribute to long-term plasma stability in astrophysical environments. We develop analytical models and conduct modified magnetohydrodynamic (MHD) simulations to examine whether radiation fields can enhance electron-proton coherence timescales. Our formulation introduces a coherence dynamics equation where radiation acts as both damping and source term. Incorporating empirical cosmic ray data (energy density approximately 1.6×10^{-12} erg cm $^{-3}$, heating rate approximately 1.7×10^{-27} erg cm $^{-3}$ s $^{-1}$), we identify a potential stability threshold and discuss implications for cosmic structure evolution. The results suggest radiation may play a more active role in plasma dynamics than previously considered, though verification against established magnetic stabilization mechanisms remains essential.

Keywords: plasma stability, radiation physics, cosmic rays, MHD simulations, astrophysical plasmas

1 Introduction

In conventional astrophysical models, radiation is typically treated as an energy loss mechanism or background field that influences plasma dynamics primarily through heating and ionization. However, the remarkable persistence of large-scale cosmic structures—such as galactic filaments maintaining coherence over billion-year timescales—suggests additional stabilizing mechanisms may be at play.

This work explores an alternative perspective within the Tanfarid Quantum-Thermodynamic Universe (TQTU) framework, which hypothesizes that continuous radiation flux may serve as an active stabilizing agent in charged fluid dy-

namics. We investigate whether radiation fields could contribute to maintaining electron-proton coherence in dilute astrophysical plasmas, complementing established stabilization by magnetic fields and turbulence.

2 Theoretical Framework

2.1 Coherence Dynamics Formulation

We propose a phenomenological model for plasma coherence evolution:

$$\frac{dC}{dt} = -\Gamma_{\text{rad}}C + S_{\text{rad}}, \quad (1)$$

where $C \in [0, 1]$ represents a normalized coherence parameter quantifying electron-proton velocity correlation, Γ_{rad} denotes the radiative damping rate, and S_{rad} represents the coherence source term from radiation fields.

The steady-state solution ($dC/dt = 0$) yields:

$$C_{\infty} = \frac{S_{\text{rad}}}{\Gamma_{\text{rad}}}. \quad (2)$$

In the absence of radiation sources ($S_{\text{rad}} = 0$), coherence decays exponentially:

$$C(t) = C_0 e^{-\Gamma_{\text{rad}} t}, \quad (3)$$

with characteristic timescale:

$$\tau_{\text{decay}} = \frac{1}{\Gamma_{\text{rad}}} \approx 3.2 \times 10^3 \text{ yr} \left(\frac{n_e}{\text{cm}^{-3}} \right)^{-1} \left(\frac{T}{10^4 \text{ K}} \right)^{1/2}. \quad (4)$$

This simplified treatment neglects complex kinetic effects but provides a first-order framework for testing the radiation stabilization hypothesis.

2.2 Radiation Pressure Effects

Incorporating radiation pressure into the momentum equation:

$$\rho \frac{D\mathbf{v}}{Dt} = -\nabla P + \mathbf{J} \times \mathbf{B} + \frac{1}{c} \mathbf{F}_{\text{rad}}, \quad (5)$$

where $\mathbf{F}_{\text{rad}} = \kappa_{\text{es}} \rho \frac{I}{c}$ represents the radiation force density, κ_{es} is the electron scattering opacity, and I is the radiation specific intensity.

This modifies the Jeans instability criterion to:

$$k_{\text{Jeans}}^2 = \frac{4\pi G \rho}{c_s^2 + \frac{1}{3} \kappa_{\text{es}} \frac{I}{c \rho}}. \quad (6)$$

For typical interstellar conditions ($I \approx 10^{-3} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$, $n_e = 0.1 \text{ cm}^{-3}$, $T = 10^4 \text{ K}$), the radiation pressure contribution becomes comparable to thermal pressure, potentially increasing the Jeans length by approximately 40% and suppressing small-scale fragmentation.

3 Numerical Methods

We implemented the coherence dynamics model within the Athena++ MHD framework, extending it to include radiation-plasma coupling terms. Our simulations adopt parameters representative of the warm interstellar medium.

Simulation parameters:

- Domain size: 1 kpc^3
- Grid resolution: 512^3
- Initial electron density: 0.1 cm^{-3}
- Initial temperature: 10^4 K
- Turbulent velocity: 100 km s^{-1} RMS dispersion
- Magnetic field: $1 \mu\text{G}$ initial strength
- Radiation source: 10^{-29} to $10^{-26} \text{ erg cm}^{-3} \text{ s}^{-1}$
- Dynamical time: 1 Myr

The radiation source term S_{rad} was varied across physically motivated values, encompassing empirical cosmic ray heating rates and interstellar radiation field intensities.

4 Results

4.1 Coherence Evolution

Our simulations reveal distinct stability regimes dependent on radiation flux:

- **Stable regime** ($S_{\text{rad}} \geq 2 \times 10^{-27} \text{ erg cm}^{-3} \text{ s}^{-1}$): coherence maintained at $C > 0.8$ over 1 Myr timescales.
- **Transition regime** ($10^{-28} < S_{\text{rad}} < 2 \times 10^{-27} \text{ erg cm}^{-3} \text{ s}^{-1}$): partial coherence with slow decay.
- **Unstable regime** ($S_{\text{rad}} \leq 10^{-28} \text{ erg cm}^{-3} \text{ s}^{-1}$): rapid decoherence with $\tau_{\text{decay}} \approx 10^3$ to 10^4 yr .

4.2 Critical Radiation Threshold

Parameter space exploration identifies a critical radiation flux for stability:

$$S_{\text{rad, critical}} = (1.7 \pm 0.5) \times 10^{-27} \text{ erg cm}^{-3} \text{ s}^{-1}. \quad (7)$$

Notably, this threshold aligns with empirical cosmic ray heating rates in the interstellar medium, suggesting that naturally occurring radiation backgrounds may contribute to plasma stability.

4.3 Spatial Structure Analysis

Spatial distribution contrasts show that radiation-supported cases maintain organized coherence, while radiation-deficient cases exhibit turbulence and coherence loss.

5 Discussion

5.1 Astrophysical Implications

- **Cosmic structure stability:** The alignment between our derived critical flux and observed cosmic ray energy density provides circumstantial support for radiation-mediated stabilization in galactic filaments and cosmic web structures.
- **Star formation regulation:** Radiation pressure effects on the Jeans criterion may contribute to the observed inefficiency of star formation, particularly in radiation-rich environments.
- **Planetary system evolution:** Low-radiation environments around faint stars might exhibit altered plasma behavior in protoplanetary disks and planetary ionospheres.

5.2 Limitations and Future Work

- The coherence parameter C remains phenomenological.
- Neglect of several stabilization mechanisms, especially magnetic fields.
- Simplified radiation-matter coupling without spectral dependence.
- Numerical resolution limits capturing of kinetic-scale phenomena.

Future work: fully kinetic treatments, JWST comparisons, parameter surveys.

6 Empirical Validation Strategies

6.1 Observational Tests

- **JWST filament analysis:** Correlate radiation field measurements with filament coherence metrics in nearby molecular clouds.
- **Radio astronomy:** Map synchrotron emission and cosmic ray distributions.
- **Gamma-ray astronomy:** Constrain cosmic ray density in stable versus unstable structures.

6.2 Numerical Validation

- Multi-code verification across different MHD frameworks.
- Radiation-MHD coupling with self-consistent transport.
- Parameter space exploration across varied environments.

7 Conclusions

Our investigation provides preliminary support for the hypothesis that radiation fields may contribute to plasma stability in astrophysical environments. Key findings:

- We developed a coherent mathematical framework describing radiation-mediated plasma stability.
- Simulations identify a critical radiation flux threshold approximately $1.7 \times 10^{-27} \text{ erg cm}^{-3} \text{ s}^{-1}$ for long-term coherence.
- This threshold aligns with empirical cosmic ray energy density.
- Radiation pressure effects may significantly modify gravitational instability criteria.

While results are suggestive, they remain speculative pending rigorous observational tests and more sophisticated numerical treatments. Nevertheless, radiation stabilization offers a potentially fruitful direction for understanding the remarkable persistence of cosmic structures.

8 Data Availability

The simulation data, analysis scripts, and model implementations are publicly available at <https://github.com/faridul1989/Radiation-Plasma-Stability>.